MISSION OPERATIONS AND COMMAND ASSURANCE: AUTOMATING AN OPERATIONS TQM TASK

Linda Welz*, Sheri Kazz, Sherrill Potts, Mona Witkowski, Kristin Bruno

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Dr., Mail Stop 125-233
Pasadena, CA 91109

Abstract

A long-term program is in progress at the Jet Propulsion Laboratory (JPL) to reduce cost and risk of mission operations through defect prevention and error management. A major element of this program, Mission Operations and Command Assurance (MO&CA), provides a system level function on flight projects to instill quality in mission operations. MO&CA embodies the Total Quality Management (TQM) principle of Continuous Process Improvement (CPI) and uses CPI in applying automation to mission operations to reduce risk and costs. MO&CA has led efforts to apply and has implemented automation in areas that impact the daily flight project work environment including Incident Surprise Anomaly tracking and reporting; command data verification, tracking and reporting; and command support data usage. MO&CA's future work in automation will take into account that future mission operations systems must be designed to avoid increasing error through the introduction of automation, while adapting to the demands of smaller flight teams,

Introduction

A long-term program is in progress at the. Jet Propulsion Laboratory (JPL) to reduce cost and risk of mission operations through defect prevention and error management. Mission operations require systems that place human operators in a demanding, high risk environment. This applies not only to mission controllers working in the control room and Deep Space Network (DSN) operators configuring and monitoring DSN operations, but also to teams that plan the missions, develop the command sequences, and analyze spacecraft performance.

* Member Technical Staff, Software Product Assurance Section, Member AIAA

The flight operations environment generally requires operators to make rapid, critical decisions and solve problems based on limited information, while closely following standard procedures (Refs. 1-3). This environment is, therefore, inherentl y risk y because each decision made is potentially mission critical.

To contain this risk at JPL, mission operations procedures (as described in Refs. 4-5) currently require intensive human reviews. In addition, when an error dots occur, rapid rework is required to ensure mission success. This strategy has worked well to reduce risk and ensure the success of JPL missions. However, the extensive human labor investment required for review and rework has substantially contributed to the overall cost of mission operations and has placed operators in stressful environments. Prevention of errors would greatly reduce both cost and risk of flight projects. Thus, the motivation of the long-term defect prevention/error management program is to contain risk in a more cost effective and human supportive manner by preventing errors rather than reworking them. The goal of this program is the management, reduction and prevention of errors.

A major element of this program is the Mission Operations and Command Assurance (MO&CA) function. MO&CA occupies a unique position in the flight project organization. As a member of the flight team MO&CA reports to flight project management. As a representative of the System Assurance Division MO&CA reports to the Office of Engineering and Review. From this position, MO&CA provides a system level function on flight projects to instill quality in mission operations. MO&CA's primary goal is to help improve the operational reliability of projects during flight. This paper describes how MO&CA embodies the Total Quality Management (TQM) principle of Continuous Process improvement (CPI) and uses CPI in applying automation to mission operations to

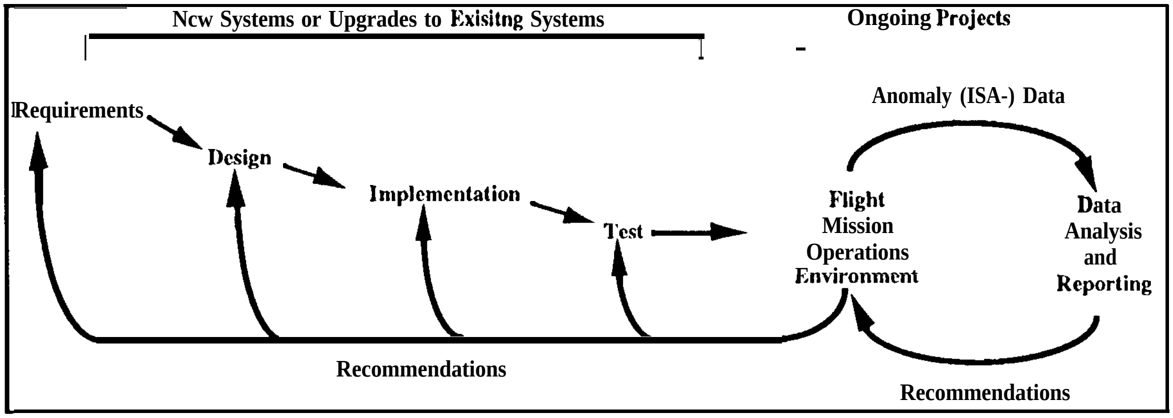

Figure 1
Total Quality Management **Model of MO&CA Continuous Process Improvement** Loops

reduce risk and costs.

MO&CA and TQM

MO&CA specifically embodies the TQM principle of CPI in which processes arc constantly examined and analyzed for opportunities for improvement. Figure 1 shows how MO&CA implements CPI in two ways. First, within ongoing projects, the mission operations environment is established and MO&CA participates as a team member. In day-to-day operations, anomalies are documented as Incident Surprise Anomaly (ISA) Reports. The ISAS then serve as data that is analyzed by MO&CA engineers for process improvement opportunities. When these opportunities are identified, MO&CA provides reports and data to support recommendations for improvement to project management. Finally, based on management approval, MO&CA helps the project implement the changes in the day-to-day mission operations environment. This technique was successfully implemented on the Voyager (VGR), Magellan (MGN), Topex/Poseidon, and Mars Observer (MO) projects.

The second way in which MO&CA implements CPI on JPL projects is on new projects or upgrades to existing projects, The recommendations that are developed from the data anal ysis on ongoing projects are used as input to system requirements on new projects. This allows new projects such as Topcx/Poseidon and MO to benefit from improvements made and experience gained on older projects such as VGR and MGN.

Automation of the MO&CA Task

Using the principle of CPI, MO&CA, in a related error analysis study (Ref. 6), identified the primary causes of errors in mission operations from recent JPL projects. Figure 2 shows that human and software errors account for 54% of flight operations errors. Many of these errors could be eliminated by automating some of the tasks performed by flight operation teams.

Several cost issues are also considered when automating flight operations tasks. Onc emphasis in applying automation has been to use existing or commercially available software to reduce costs when developing new applications. Another consideration has been ease of usc for both the end user and developer. This reduces both development and training cost and time. Ease of usc also minimizes risk that may be introduced with the operations of a complex system. A third consideration for cost reduction has been to automated tasks on existing platforms, thus eliminating the cost of new hardware.

MO&CA, as a member of the flight team, has led efforts to apply and has implemented automation in areas that impact the daily flight project work environment. MO&CA's areas of automation have included ISA tracking and reporting, command data verification, tracking and

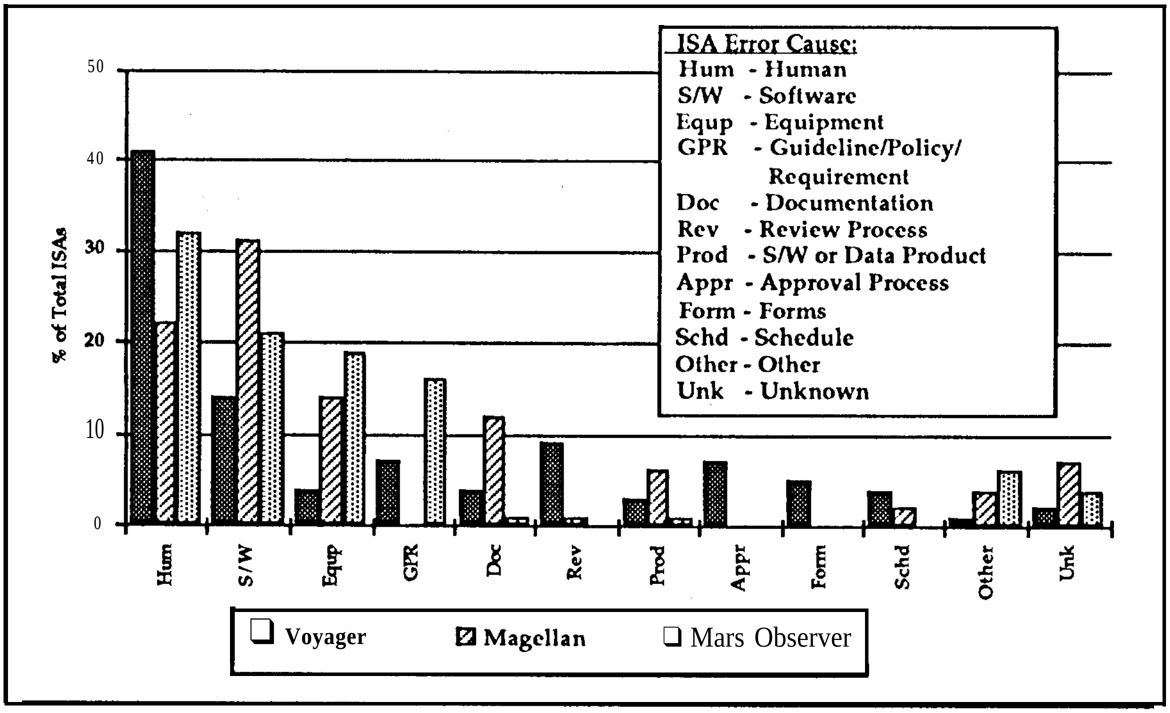

Figure 2
Comparison of ISA Analysis - Voyager, Magellan, Mars Observer

reporting, and command support data usage. Each of these areas is described below.

<u>Anomaly Reporting</u>

ISA reports are the primary data source for analysis of mission operations problems. These data are used both daily by MO&CA managers and engineers, and historically to analyze errors (Ref. 6). MO&CA's first automation effort was therefore to increase its own team efficiency by improving the usability and accessibility of ISA reports. MO&CA designed, developed and implemented an ISA database for the MGN project and automated the reporting and tracking functions needed to support the project,

MO&CA's primary anomaly reporting task included the preparation of Monthly Anomaly Report. This report is used to assess progress in resolving project issues. Preparation of this report used the a large portion staff time. The thrust of the MO&CA automation was to streamline the reporting process by improving printing speed, standardizing content, and having software perform the numeric data collection automatically. Before automation, this report took over 7 days to complete After automation, as shown in Table 1, the report could be prepared in 4 to 5 hours.

Time was spent in the initial development stages to ensure that the databases, analyses, and report material would be responsive to customer needs. The customer under consideration was first and foremost the Magellan project. However, included in the customer list was the MGN MO&CA Team, future flight projects, and future MO&CA Teams. Customer requirements included detailed reports, report graphics, and timely report distribution. Once the customer requirements were established, MO&CA standardized fields in the ISA database to facilitate data utilization. This enabled MO&CA to respond more readily to customer requests. The next step was to automate.

The most time consuming steps were earmarked for automation first. Several methods of automating were used:

(1) Writing programs to replace the tedious and error prone monthly typing of database commands to obtain numerical information for tables and

Report Item	Original Process Time	Automated Process Time	Automation Steps
Table	3 Days	1 Hour	• Write Counting/Printing Program • Standardize Table Output • Standardize Numeric Content
Graphs	3 Days	2 Hours	• Write Counting/Printing Program • Standardize Numeric Content • Program Spread Sheet • Standardize Plots • Save Plot Formats
Listing	1 Day	1 Hour	• Standardize Commands • Standardize Report Listing • Save Commands • Save Report Format
Memo	1 Hour	1/2 Hour	• Standardize Memo • Save Distribution List • Save Memo
Total Report	**~7 Days**	**~ 4 Hours**	6 1/2 Days Saved/ Month

Table 1. Monthly Anomaly Report: Original Process Time, Automated Process Time, and Automation Steps

graphs. These programs replaced 600 hand typed lines of database commands.

(2) Creating spreadsheets to automatically calculate totals and perform cross checks when new numbers were entered. Over 400 totals and 10 cross cheeks previously had been hand calculated each month,

(3) Standardizing and saving command sets to produce listings.

(4) Standardizing and saving a memo for updating.

(5) Setting up a Local Area Network (LAN) so more than onc person could work on the report at one time, if necessary.

(6) Using a laser printer instead of a slow line printer. Laser printing was 10 times faster and was performed off-line. Thus, team computers were freed for other work while the print data were spooled,

(7) Training each member of the MO&CA Team to produce this entire report and then alternating responsibility among the Team for various sections of the report,

The automation process was accomplished (as time permitted) over a period of a year and a half. The cost was 15 days of labor to design, develop, and test the software, and to train MO&CA engineers to use the application. When the automation was complete, the overall net savings was over 6 work days per month (33%) for the MO&CA Team.

Advantages to the project were more than time savings. After seeing the automated report several teams, Spacecraft, Radar, and Data Management, requested monthly anomaly listings tailored to their team issues. Automation enhanced ISA trend analyses and enabled MO&CA to show recurring problems and recommend solutions to eliminate them.

Coremand Activity

MO&CA also analyzes command activity in parallel with ISA reports. This task was especially challenging for the Topex/Poseidon project MO&CA team duc to the volume of commands and the frequent changes associated with the Tracking and Data Relay Satellite (TDRS) communications system. Automating command data collection was therefore a neccessit y.

Two programs were developed: onc to track all commands transmitted to the spacecraft, and a second onc to reconcile all commands received by the spacecraft with those transmitted. This information is used to verify all planned and unplanned commands and for command report generation. Command collection automation also enables the MO&CA team to analyze transmission versus reception rapidly to identify and correct errors.

While working with the command process, the Topcx/Poseidon MO&CA team noted the human intensive effort in command verification. A repetitive task such as command validation tends to be error prone and increase risk. The MO&CA team developed a program which automates verification of command transmission timing. A special program was also developed for the Navigation Team which collects all TDRS allocation and configuration information, This information is then provided to the Flight 'Dynamics Facility to assist in orbit determination.

MO&CA automated command tracking and verification processes for usc by the MO&CA team. However, the results were so successful that the entire flight team requested usc of the information. The automation has improved the flight team's ability to track command transmission reconciling them with planned and real-time command request. Command validation efficiency has increased and therefore error probability y has been reduced. Command trend analysis, problem resolution, and report generation has been made more efficient and accurate. The information provided is also being kept as history files for the Topcx/Poseidon project and is being used to generate "lessons learned".

Team Communicanti o n

MO&CA also tracks ancillary command data, data associated with command development. These data files are often used by several learns on a flight project. It is therefore imperative that these files be accurate and timely. On the Mars Observer Project MO&CA noted problems with inter-team communication and use of these ancillary command data. Four separate operations teams, Spacecraft, Planning and Sequencing, Mission Control, and MO&CA, maintained separate command related data files that resulted in redundant and incongruous data. Manual transcription and interpretation errors occurred frequently and unnecessarily increased risk. MO&CA noted that these problems in the command design and command file development had led teams to take shortcuts that subsequently increased risk of error.

MO&CA's first step in automating the usc of the ancillary data files was to gather the file structures and reports from each team and identified data producers, data users, and redundant data usage. MO&CA then initiated and led a working group that analyzed each team's data needs and identified and prioritized requirements for the development of a single command data system, The working group defined the requirements for a database to track ancillary command data.

The Mars Observer Command Tracking Database was developed by the Planning and Sequence Team and implemented on a workstation. Team members have access via a local area network. Access is menu drive and controlled by scripts. Scripts were developed to be flexible. An outline of the script is provided to each team desiring access. The team can then adapt the script to team specific needs. Tables arc owned by producing team who is responsible for table content, but read access is available to all teams, Consistent accurate data is available to the entire flight team in real-time.

The Future of MO&CA Automation

MO&CA's initial efforts to implement automation in mission operations were based on two concerns. The primary concern was risk reduction. Since human and software errors were the major causes of operations errors, these two areas were targeted. Automating repetitive, error prone tasks such as command validation and verification greatly reduced risk. Automating ISA trend analysis improved MO&CA's ability to identify and eliminate repetitive errors, also reducing risk, Providing automated tracking of ancillary command data ensured that data used to developed spacecraft commands were accurate, thus reducing risk of command error.

The second concern for automation was cost reduction. The tasks that were the most time consuming were automated. Report generation was the first candidate for automation.

Command count reconciliation (commands planned, commands transmitted, and commands received) was also a time consuming task that was made more cost effective and efficient by automation.

Many other efforts are currently underway to apply automation to the flight operations environment to reduce cost and risk (Ref. 7). Automation applied to mission operations for future JPL flight project must also take into account that future missions will have smaller spacecraft and flight teams (Refs. 8-9). Development times will be reduced and the teams that design and build the spacecraft will also staff the mission operations teams.

For automation to be effective it must be applied wisel y (Ref. 10). Automation that does not take into account human factors can introduce error. This is the "irony of automation" (Ref. 11). Automation should allow computers to do what they do well, while supporting the human clement of flight operations enabling the flight teams to perform the tasks that they do well even more efficiently and effectively.

Future mission operations systems must be designed to avoid increasing error through the introduction of automation, as well as adapting to the demands of smaller flight teams. MO&CA future work in automation will be done with these two principles as the underlying basis,

Conclusion

MO&CA, using the TQM principle of CP1, works with flight teams to instill quality into mission operations. MO&CA identified human and software errors as the primary causes of errors in mission operations in recent JPL projects. To eliminate many of these errors and reduce both cost and risk, MO&CA worked to automate mission operations tasks for ISA tracking and reporting, command data verification, tracking and reporting, and command support data usage. As MO&CA and mission operations tasks continue to be automated, human factors will be taken into account to avoid the irony of automation and ensure new systems improve MO&CA and mission operations tasks.

Acknowledgment

The Mission Operations and Command Assurance effort is carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

The effort of many people from the JPL Office of Engineering and Review went into the MO&CA work on JPL projects. The authors would like to acknowledge their efforts by recognizing the participants: Al Brejcha, Anna Bruhn, Grant Faris, Larkin Hamilton, Sara Hyman, Kil-Sun Kang, Mark Kennedy, Farinaz Kavousirad, Young Kim, Robyn Lutz, George Nichols, Anne Phu, Irwin Plitt, Richard Santiago, Mitch Staff, John Schlue, Hui-Yin Shaw, William Shipley, Lowell Thompson, Greg Welz.

References

1. Horvath, J. C., and Perry, L.P. 1990. Hypercubes for critical spacecraft verification. In Proceeding of AIAA Second International Symposium on Space Information Systems, Pasadena, Ca., 1285-1291.

2. Linick, T.D. 1985. Spacecraft commanding for unmanned planetary missions: the uplink process. Journal of the British Interplanetary Society, 38:450-457.

3. Muratore, J.F., Heindel, T. A., Murphy, T.B. Rasmussen, A.N. and McFarland, R.Z. 1990. Real-time data acquisition at mission control. Communications of the ACM, 33(12):18-31.

4. Haynes, N.R. 1985. Planetary mission operations: an overview. Journal of the British Interplanetary Society, 38:435-438.

5. McLaughlin, W. 1987. How to feed a spacecraft, Spaceflight, 29:38-40.

6. Bruno, K.J., Welz, L.L., Barnes, G. M., and Sherif, J.S. 1992. Analyzing human errors in flight mission operations. A Paper presented at the Sixth Annual Space Operations, Applications, and Research Conference, NASA Johnson Space Flight Center, Houston, Texas, August 4-6.

7. Montemerlo, M. 1993. Strategic Directions for NASA Space Technology and Commercial Programs. Keynote Address, Seventh Annual

Space Operations, Applications, and Research Symposium. Houston, Texas; August 3-5,1993.

8. Cassini, K., and Spear, A.J. 1992. Low Cost Spacecraft: The Wave of the Future [Videotape]. Pasadena, Ca.: Jet Propulsion Laboratory.

9. Stone, E.C. 1992, Total Quality Management Seminar [Videotape]. Pasadena, Ca.: Jet Propulsion Laboratory.

10. Reason, James. 1990. Huamn Error. Cambridge University Press, Ncw York.

11. Bainbridge, Lisa. 1987. Ironies of Automation. In New Technology and Human Error. Ed. J. Rasmussen, K. Duncan, and J. Leplat. John Wiley & Sons Ltd., London. pp. 271-283.